Catalog of Global Emissions Inventories and Emissions Inventory Tools for Black Carbon

Draft Report

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Introduction

Emissions inventories for climate change studies have focused primarily on greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and various halogenated compounds.[1] However, various components of fine particulate matter ($PM_{2.5}$) in the atmosphere also have climate-forcing impacts, either contributing to or offsetting the effects of greenhouse gases.[2] In particular, black carbon particulate matter (BC) has recently been identified as an important contributor to radiative heating of the atmosphere.[3] Organic carbon particulate matter (OC), which is often emitted along with BC, may act to offset some of the global warming impact of BC emissions.[2]

Most of the important sources of greenhouse gases also are important sources of health-related pollutants. Likewise, BC and OC particulate matter are emitted primarily from combustion sources, which are also important sources of health-related pollutants. Because of these overlaps, measures to reduce climate-forcing emissions often would have collateral benefits by reducing emissions of health-related pollutants, and vice versa. Improved emissions inventory methodologies and tools developed for health-related pollutants can also provide opportunities for improving climate change emissions inventories (and vice versa).

A better characterization of worldwide emissions of climate forcing and health-related pollutants is needed to improve the understanding of overlapping benefits for emission reduction strategies both in the U.S. and abroad. The improved characterization of emissions will help in two ways: (1) by quantifying the most efficient strategies for improving both global warming and health-related problems, and (2) by identifying sources that are under-reported or missing from different emissions inventories. A full characterization of these under-reported or missing sources could alter the priorities of programs designed to mitigate both health-related and global climate impacts.

The purpose of the report is to twofold. First, a catalog is developed of country-specific and regional inventories for climate forcing pollutants and health related pollutants. The purpose of this catalog is to assist in the identification of opportunities for transfer of factors and methods among the different types of emissions inventories. Second, a more in depth review is made of tools and factors available to estimate particulate BC emissions. The purpose of this review is to assist in identifying and prioritizing opportunities for improving U.S. and worldwide inventories of BC emissions. It must be noted that this report represents only a cursory first look at the available data. A CD-ROM companion to the report compiles available data from the catalogued emissions inventories.

Catalog of Global Emissions Inventories and Methods

Regional and Global Greenhouse Gas Inventories

Several organizations have produced regional and/or global greenhouse gas inventories in varying degrees of resolution, ranging from a global 1^o x 1^o latitude/longitude grid (about 100 kilometers x 100 kilometers near the equator) to country-wide inventories. Many of these inventories were developed to fulfill various international obligations, such as the United Nations Framework Convention on Climate Change (UNFCCC).[1] This convention is discussed in detail in later sections. In order to be compatible with the UNFCCC reporting format, many organizations used the Intergovernmental Panel on Climate Change (IPCC)[4] or comparable methodologies. Others, however, relied on unique models and methods. Table 1 summarizes these inventories, including the sectors and pollutants covered.

The following sections discuss background information and methodologies used to produce these inventories. It must be noted that the table does not represent a comprehensive list, but rather catalog based on readily available information. A CD-ROM companion to this report compiles available data from the catalogued emissions inventories.

CORINAIR 94

The Core Inventory Air (CORINAIR) 94 database is the air emissions inventory for participating European countries in 1994[5]. The European Environment Agency (EEA) designated the European Topic Centre on Air Emissions (ETC/AE) to assist participating countries in reporting their national emissions estimates as required under various international obligations. These obligations include those under the UNFCCC, as well as the Convention on Long-Range Transboundary Air Pollution (LRTAP)[6]. In both cases, many European countries used the CORINAIR methodology to produce their greenhouse gas, criteria pollutant, and toxic air pollutant inventories.

The database included in this report presents a summary of emission estimates according to the LRTAP guidelines, described below. The greenhouse gases and other climate forcing emissions include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), carbon monoxide (CO), nitrogen oxides (NO_x), non-methane volatile organic carbon (NMVOC), sulfur dioxide (SO_2), and ammonia (NH_3). The inventory also includes nine heavy metals and ten persistent organic pollutants (POPs).

EDGAR V2.0 database

The Emission Database for Global Atmospheric Research (EDGAR)[7] was developed jointly by the Netherlands Organization for Applied Scientific Research (TNO) and RIVM. This comprehensive database stores inventories of direct and indirect anthropogenic greenhouse gas emissions both on a per country basis as well as on a 1^o x 1^o grid. Using 1990 as its base year, EDGAR inventories CO_2, CH_4, halocarbons (HC), N_2O, CO, NOx, VOC, and SO_2 for sectors including fossil fuel and biofuel combustion, industrial processes, solvent use, land use, and waste treatment.

Table 1. Emissions Inventories for Climate Forcing Pollutants

Inventory and description	Year *	Pollutants included	Source Categories **	Reference
Regional and Global Inventories				
CORINAIR 94	1994	CO_2, CH_4, N_2O, CO, NO_x, VOC, SO_2, Particulate Organic Carbon	SNAP level 1 sectors[a]	CORINAIR website[5]
EDGAR – 1° latitude x 1° longitude	1990	CO_2, CH_4, N_2O, CO, NO_x, VOC, SO_2,	Fossil Fuel (combustion, non-combustion), Biofuel, Industrial Processes, Land Use, Waste	EDGAR online database[7]
EEA – EU15 countries, Latvia	1999	CO_2, CH_4, N_2O, HFC, PFC, SF_6	Energy, Industry, Transport, Agriculture, Waste, Other	EEA online database[8]
EIA international report	1998	CO_2	Coal, Natural Gas, Petroleum, Other	EIA document[9]
GEIA – 1° lat x 1° long	1994	CO_2, CH_4, CFC, N_2O, CO, NO_x, VOC, SO_2, Reactive Cl	Fossil Fuels, Biomass	GEIA online database[10]
LRTAP – Europe and N. Amer.[b]	1998	CO_2, CO, NO_x, VOC, SO_2,	Annual Aggregated Emissions, SNAP level 1 sectors	LRTAP website on UNECE[6]
RAINS-ASIA – 23 Asian countries[c]	1990	CO_2, CH_4, CO, NO_x, NMHC, SO_2	Biofuels (including Firewood, Crop Residue, Animal Waste), Fossil Fuels	Streets, David [11,12,13]

[a]These sectors include industrial and non-industrial combustion, energy combustion, production processes, extraction, solvents, road transport, other mobile sources, waste treatment, and agriculture and forestry.

[b]Countries include Armenia, Austria, Belarus, Belgium, Bosnia and Herzegovina, Bulgaria, Canada, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Macedonia, Georgia, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Liechtenstein, Lithuania, Luxembourg, Moldova, Monaco, Netherlands, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom, United States, Yugoslavia, European Community.

[c]Countries include Bangladesh, Bhutan, Brunei, Cambodia, China, Hong Kong, India, Indonesia, Japan, North and South Korea, Laos, Malaysia, Mongolia, Myanmar, Nepal, Pakistan, Philippines, Singapore, Sri Lanka, Taiwan, Thailand, Vietnam, Asia

* Year of most recent inventory.

** Unless otherwise specified, the Energy sector includes all stationary and mobile combustion sources, and Agriculture includes biomass burning.

Table 1. Emissions Inventories for Climate Forcing Pollutants (continued)

Inventory and description	Year *	Pollutants included	Source Categories **	Reference
UNFCCC – Annex I Parties [d]	1998	CO_2, CH_4, N_2O, HFC, PFC, SF_6, CO, NO_x VOC, SO_2	Energy, Industry, Agriculture, Land Use/Forestry, Waste, International Bunkers	UNFCCC website[1]
World Bank – worldwide	1998	NO_x, SO_2, Particulates	Major City	World Bank Document[14]
Country-specific Inventories				
Argentina	1997	CO_2, CH_4, HCFC, PFC, SF_6, N_2O, CO, NO_x, VOC	Energy, Industry, Agriculture, Waste	Argentina National Communication[15]
Armenia	1996	CO_2, CH_4, N_2O, CO, NO_x, VOC	Energy, Industry, Agriculture, Land Use/Forestry, Waste	Armenia National Communication[16],
Australia	1995	CO_2, CH_4, HCFC, PFC, SF_6, N_2O, CO, NO_x, VOC	Energy, Industry, Agriculture, Land Use/Forestry, Waste, Solvents	Australia 2nd National Communication[17]
	1999	CO_2, CH_4, HCFC, PFC, SF_6, N_2O, CO, NO_x, VOC	Energy, Industry, Agriculture, Solvents, Land Use/Forestry, Waste	Australia National Greenhouse Gas Inventory[18]
Austria	1995	CO_2, CH_4, HCFC, PFC, SF_6, N_2O, CO, NO_x, VOC	Energy, Transport, Industry, Small Consumers, Agriculture, Land Use/Forestry, Waste	Austria 2nd National Communication[19]
Azerbaijan	1994	CO_2, CH_4, N_2O, CO, NO_x, VOC	Energy, Industry, Agriculture, Land Use, Waste	Azerbaijan National Communication[20]
Bangladesh	1990	CO_2, CH_4	Energy, Agriculture, Forestry	Ahmed, Ahsan[21]
	1990	CO_2, CH_4, N_2O,CO, NO_x,	Energy, Industry, Agriculture, Land Use/Forestry, Waste	Climate Change Asia website[22]
Belgium	1995	CO_2, CH_4, HCFC, PFC, SF_6, N_2O, CO	Energy, Industry, Agriculture, Forestry, Waste	Belgian 2nd National Communication[23]
	1998	CO_2, CH_4, HCFC, PFC, SF_6, N_2O, CO, NO_x VOC, SO_2	Energy, Industry, Agriculture, Forestry, Waste, Solvents	Belgian Federal Government Online[24]
Brazil	1994	CO_2, CH_4, N_2O, NO_x	Agriculture, Industry, Energy, Waste, Solvents	Brazil National Communication[25]
Bulgaria	1995	CO_2, CH_4, HCFC, PFC, SF_6, N_2O, CO, NO_x, VOC	Energy, Industry, Transport, Agriculture, Forestry/Land Use, Waste	Bulgaria 2nd National Communication [26]

[d]Countries include: Australia, Austria, Belgium, Bulgaria, Canada, Czech Republic, Denmark Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Liechtenstein, Lithuania, Luxembourg, Monaco, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Switzerland, Ukraine, United Kingdom, United States

* Year of most recent inventory.
** Unless otherwise specified, the Energy sector includes all stationary and mobile combustion sources, and Agriculture includes biomass burning.

Table 1. Emissions Inventories for Climate Forcing Pollutants (continued)

Inventory and description	Year *	Pollutants included	Source Categories **	Reference
Canada	1995	CO_2, CH_4, HCFC, PFC, SF_6, N_2O, CO, NO_x, VOC, CF4, C2F6	Energy, Industry, Transport, Agriculture, Forestry/Land Use, Waste	Canada 2nd National Communication[27]
Cape Verde	1995	CO_2, CH_4, N_2O	Energy, Transport, Agriculture	Cape Verde National Communication[28]
Chile	1994	CO_2, CH_4, N_2O, CO, NO_x, VOC	Energy, Industry, Agriculture, Land Use, Waste, Solvents	Chile National Communication[29]
	1993	CO_2, CH_4, N_2O, CO, NO_x, SO_2, NMVOC	Energy, Industry, Forestry	World Energy Council Report[30]
China	1990	CO_2, CH_4, N_2O,CO, NO_x,	Energy, Industry, Agriculture, Waste, Land Use/Forestry	Climate Change Asia website[22]
	1995	CO, NO_x, SO_2	Energy, Industry, Transport, Domestic, Biofuels, Other; also by Region	Streets, David G. and S.T. Waldhoff[31]
Cook Islands	1994	CO_2, CH_4, N_2O	Energy, Industry, Agriculture, Land Use, Waste, Solvents	Cook Islands National Communication[32]
Cote d'Ivoire	1996	CO_2, CH_4, N_2O, CO, NO_x	Energy, Industry, Agriculture, Land Use, Waste, Solvents	Cote d'Ivoire National Communication[33]
Czech Republic	1995	CO_2, CH_4, HFC, PFC, SF_6, N_2O, NO_x, CO, VOC	Energy, Industry, Transport, Agriculture, Land Use/Forestry, Commercial, Residential, Institutional	Czech Republic 2nd National Communication[34]
Denmark	1996	CO_2, CH_4, HFC, PFC, SF_6, N_2O, CO, NO_x, VOC, SO_2	Energy, Industry, Agriculture, Solvents, Land Use, Waste, Transport	Denmark 2nd National Communication[35]
Ecuador	1990	CO_2, CH_4, N_2O, CO, NO_x, VOC	Energy, Industry, Agriculture, Land Use /Forestry, Waste	Ecuador National Communication [36]
Egypt	1990	CO_2, CH_4, N_2O	Energy, Industry, Agriculture, Waste	Egypt National Communication[37]
El Salvador	1995	CO_2, CH_4, N_2O, CO, NO_x	Energy, Industry, Agriculture, Waste	El Salvador National Communication[38]
Estonia	1996	CO_2, CH_4, N_2O	Energy, Industry, Transport, Agriculture, Land Use/Forestry, Waste	Estonia 2nd National Communication[39]
European Community	1999	CO_2, CH_4, HFC, PFC, SF_6, N_2O, CO, NO_x, VOC, SO_2	Energy, Industry, Agriculture, Transport, Land Use/Forestry, Waste	EC Greenhouse Gas Inventory[40]

* Year of most recent inventory.
** Unless otherwise specified, the Energy sector includes all stationary and mobile combustion sources, and Agriculture includes biomass burning.

Table 1. Emissions Inventories for Climate Forcing Pollutants (continued)

Inventory and description	Year *	Pollutants included	Source Categories **	Reference
Finland	1995	CO_2, CH_4, N_2O, CO, NO_x, VOC, SO_2	Energy, Industry, Agriculture, Land Use/Forestry, Waste	Finland 2nd National Communication[41]
France	1995	CO_2, CH_4, CO, N_2O, NO_x, VOC, SO_2	Energy, Industry, Agriculture, Domestic/Commercial	France 2nd National Communication[42]
Georgia	1997	CO_2, CH_4, N_2O, CO, NO_x, VOC, SO_2	Energy, Industry, Transport, Agriculture, Forestry	Georgia National Communication[43]
	1996	CO_2, CH_4, CO, N_2O, NO_x	Energy, Industry, Agriculture, Forestry, Waste	Georgia Climate Change website[44]
Germany	1990	CO_2, CH_4, N_2O, CO, NO_x,VOC	Energy, Industry, Agriculture, Land Use/Forestry, Waste, Solvents	Germany National Communication[45]
Ghana	1996	CO_2, CH_4, N_2O	Energy, Industry, Agriculture, Land Use/Forestry, Waste	Ghana National Communication[46]
Greece	1995	CO_2, CH_4, N_2O, CO, NO_x, VOC	Energy, Industry, Agriculture (excluding burning)	Greece 2nd National Communication[47]
Honduras	1995	CO_2, CH_4, N_2O, CO, NO_x, VOC	Energy, Industry, Agriculture, Land Use, Waste	Honduras National Communication [48]
Hungary	1995	CO_2, CH_4, N_2O, CO, NO_x, VOC	Energy, Industry, Mobile Sources, Forestry, Waste, Commercial, Residential	Hungary 2nd National Communication[49]
Iceland	1995	CO_2, CH_4, PFC, HFC, SF_6, N_2O, CO, NO_x, VOC, SO_2	Energy, Industry, Agriculture, Land Use/Forestry, Waste, Solvents	Iceland 2nd National Communication[50]
India (by state/region)	1995	CO_2, CH_4, N_2O, NO_x, HC, SO_2	Coal, Oil products, Natural Gas, Industry processes, Indirect emissions	Climate Change India website[22]
	1995	CO_2, CH_4, N_2O, NO_x, SOx	Coal, Petroleum, Natural Gas, Industry Processes, Transport, Electric Utilities, Livestock, Waste	Garg et al.[5152]
Indonesia	1994	CO_2, CH_4, N_2O, CO, NO_x, NMHC, CF_4, C_2F_6,	Energy, Industry, Agriculture, Waste, Solvents, Land Use/Forestry, Biofuels	Indonesia National Communication[53]
	1990	CO_2, CH_4, N_2O,CO, NO_x,	Energy, Industry, Agriculture, Land Use/Forestry, Waste	Climate Change Asia website[22]
Ireland	1994	CO_2, CH_4, N_2O, CO, NO_x, VOC	Energy, Industry, Waste	Ireland 2nd National Communication[54]
Italy	1994	CO_2, CH_4, PFC, HFC, SF_6, N_2O, CO, NO_x, VOC, SO_2	Energy, Industry, Agriculture, Land Use/Forestry, Waste, Solvents, Other (bunkers)	Italy 2nd National Communication[55]

* Year of most recent inventory.

** Unless otherwise specified, the Energy sector includes all stationary and mobile combustion sources, and Agriculture includes biomass burning.

Table 1. Emissions Inventories for Climate Forcing Pollutants (continued)

Inventory and description	Year *	Pollutants included	Source Categories **	Reference
Jamaica	1994	CO_2, CH_4, N_2O	Energy, Industry, Agriculture, Land Use/Forestry, Waste	Jamaica National Communication [56]
Japan	1996	CO_2, CH_4, HFC, PFC, SF_6, N_2O, CO, NO_x, VOC, NMHC, SO_2	Energy, Industry, Agriculture, Bifuels, Land Use/Forestry, Waste, Solvents, Other (bunkers)	Japan 2nd National Communication[57]
Jordan	1994	CO_2, CH_4, N_2O	Energy, Industry, Agriculture, Land Use/Forestry, Waste, Solvents, Other (bunkers)	Jordan National Communication[58]
Kazakhstan	1994	CO_2, CH_4, N_2O, CO, NO_x, VOC	Energy, Industry, Agriculture, Waste, Land Use/Forestry	Kazakhstan National Communication[59]
Kiribati	1994	CO_2, CH_4, N_2O, CO, NO_x	Energy, Industry, Agriculture, Land Use /Forestry, Solvents	Kiribati National Communication[60]
Korea	1990	CO_2, CH_4, N_2O, CO, NO_x, VOC, NMHC	Energy, Industry, Agriculture, Biofuels, Land Use /Forestry	Korea National Communication[61]
Latvia	1990	CO_2, CH_4, N_2O, CO, NO_x, VOC	Energy, Industry, Agriculture, Land Use /Forestry, Waste, Solvents	Latvia National Communication[62]
Lebanon	1994	CO_2, CH_4, HFC, PFC, SF_6, N_2O, CO, NO_x, VOC, SO_2	Energy, Industry, Solvents, Agriculture, Land Use /Forestry, Waste	Lebanon National Communication[63]
Lithuania	1990	CO_2, CH_4, N_2O, CO, NO_x, VOC	Energy, Industry, Solvents, Agriculture, Land Use /Forestry, Waste	Lithuania National Communication[64]
Luxembourg	1995	CO_2, CH_4, N_2O, CO, NO_x, NMHC, VOC, SO_2	Energy, Mobile sources, Agriculture, Extraction/distribution of fossil fuels, Commercial/Residential, Production processes, Waste, Solvents	Luxembourg National Communication[65]
	1994	CO_2, CH_4, N_2O, CO, NO_x, NMVOC, SO_2, NH_3	SNAP Level 1 categories[a]	CORINAIR database[5]
Malaysia	1990	CO_2, CH_4, N_2O,CO, NO_x,	Energy, Industry, Agriculture, Land Use/Forestry, Waste	Climate Change Asia website[22]
	1994	CO_2, CH_4, N_2O	Energy, Industry, Agriculture, Land Use /Forestry, Waste	Malaysia National Communication[66]
Mali	1995	CO_2, CH_4, N_2O, CO, NO_x, VOC	Energy, Industry, Agriculture	Mali National Communication[67]
Malta	1994	CO_2, CH_4, N_2O, CO, NO_x, NMVOC, SO_2, NH_3	Energy, Industry, Transport, Agriculture, Waste, Solvents, Non-Industry combustion, Production processes, Fossil Fuel Extraction	CORINAIR94 database[1]

* Year of most recent inventory.

** Unless otherwise specified, the Energy sector includes all stationary and mobile combustion sources, and Agriculture includes biomass burning.

Table 1. Emissions Inventories for Climate Forcing Pollutants (continued)

Inventory and description	Year *	Pollutants included	Source Categories **	Reference
Marshall Islands	1996	CO_2, CH_4	Energy, Agriculture, Waste	Marshall Islands National Communication[68]
Mauritius	1995	CO_2, CH_4, N_2O, CO, NO_x, NMVOC, SO_2	Energy, Industry, Solvent, Agriculture, Land Use, Waste, Other	Mauritius National Communication[69]
Mexico	1997	CO_2, CH_4, N_2O, CO, NO_x, VOC, SO_2	Energy, Industry, Mobile Sources, Agriculture, Land Use /Forestry, Waste, Gas production	Mexico National Communication[70]
	1994	CO, NO_x, HC, SO_2, PM	Industry, Transport, Services	Data from Mexico climate change website[71]
Moldova	1998	CO_2, CH_4, N_2O, CO, NO_x, VOC, SO_2	Energy, Industry, Agriculture, Land Use /Forestry, Waste, Solvents	Moldova National Communication [72],
Mongolia	1990	CO_2, CH_4, N_2O, CO, NO_x	Energy, Industry, Agriculture, Land Use /Forestry, Waste	Dagvadorj, Damdin[73] (hard copy only)
Nauru	1994	CO_2, CH_4, N_2O	Energy, Industry, Agriculture, Land Use /Forestry, Waste, Solvents	Nauru National Communication[74]
Netherlands	1995	CO_2, CH_4, HFC, PFC, FIC, SF_6, N_2O, CO, NO_x, VOC, SO_2	Energy, Industry, Agriculture, Land Use /Forestry, Waste	Netherlands' National Communication[75]
New Zealand	1995	CO_2, CH_4, HFC, PFC, SF_6, N_2O, CO, NO_x, VOC, SO_2	Energy, Industry, Agriculture, Land Use /Forestry, Solvents	New Zealand 2nd National Communication [76]
Niger	1997	CO_2, CH_4, N_2O	Energy, Industry, Agriculture, Land Use /Forestry, Waste	Niger National Communication[77]
Norway	1995	CO_2, CH_4, HFC, PFC, SF_6, N_2O, CO, NO_x, VOC, SO_2	Energy, Industry, Agriculture, Land Use, Waste, Solvents	Norway 2nd National Communication[78]
Pakistan	1990	CO_2, CH_4, N_2O,CO, NO_x,	Energy, Industry, Agriculture, Waste, Land Use/Forestry	Climate Change Asia website[22]
Panama	1994	CO_2, CH_4, CO, NO_x, VOC	Energy, Industry, Agriculture, Land Use, Waste, Solvents	Panama National Communication[79]
Philippines	1994	CO_2, CH_4, CO, N_2O, NO_x, VOC, NMHC, SO_2	Energy, Industry, Agriculture, Biofuels, Waste, Land Use /Forestry	Philippines National Communication[80]
	1990	CO_2, CH_4, N_2O,CO, NO_x,	Energy, Industry, Agriculture, Land Use/Forestry, Waste	Climate Change Asia website[22]
Poland	1994	CO_2, CH_4, N_2O	Energy, Industry, Agriculture, Land Use /Forestry, Waste	Poland 2nd National Communication[81]

* Year of most recent inventory.
** Unless otherwise specified, the Energy sector includes all stationary and mobile combustion sources, and Agriculture includes biomass burning.

Table 1. Emissions Inventories for Climate Forcing Pollutants (continued)

Inventory and description	Year *	Pollutants included	Source Categories **	Reference
Portugal	1994	CO_2, CH_4, N_2O, CO, NO_x, NMVOC	Energy, Industry, Land Use/Forestry, Waste, Solvents	Portugal 2nd National Communication[82]
Romania	1991	CO_2, CH_4, N_2O, CO, NO_x, VOC	Energy, Industry, Mobile Sources, Waste	Romania 2nd National Communication[83]
Russian Federation	1990	CO_2, CH_4, N_2O, CO, NO_x, VOC	Energy, Industry, Agriculture, Waste	Russia National Communication[84]
Samoa	1994	CO_2, CH_4, N_2O	Energy, Industry, Agriculture, Land Use /Forestry, Waste	Samoa National Communication [85]
Senegal	1994	CO_2, CH_4, CFC, N_2O, CO, NO_x	Energy, Industry, Agriculture, Land Use/Forestry, Waste	Senegal National Communication[86]
Seychelles	1995	CO_2, CH_4, N_2O, CO, NO_x, VOC	Energy, Industry, Agriculture, Land Use/Forestry, Waste	Seychelles National Communication[87]
Singapore	1994	CO_2, CH_4, N_2O, CO, NMHC	Energy, Industry, Biofuels, Agriculture, Land Use/Forestry, Waste	Singapore National Communication[88]
Slovak Republic	1994	CO_2, CH_4, HFC, PFC, SF_6, N_2O, CO, NO_x, VOC, SO_2	Energy, Industry, Agriculture, Waste	Slovak Republic 2nd National Communication[89]
Spain	1994	CO_2, CH_4, N_2O, CO, NO_x, VOC	Energy, Industry, Agriculture, Land Use/Forestry, Waste, Solvents	Spain 2nd National Communication[90]
Sri Lanka	1990	CO_2, CH_4, N_2O,CO, NO_x,	Energy, Industry, Agriculture, Waste, Land Use/Forestry	Climate Change Asia website[22]
St. Vincent and Grenadines	1997	CO_2, CH_4, N_2O, CO, NO_x, VOC, SO_2	Energy, Industry, Agriculture, Land Use/Forestry, Waste	St. Vincent and Grenadines National Communication[91]
Sweden	1995	CO_2, CH_4, HFC, PFC, SF_6, N_2O, CO, NO_x VOC, SO_2,	Power/district heating plants, Other Energy, Industry, Transport, Agriculture, Waste, Solvents, Residential/Commercial	Sweden 2nd National Communication[92]
Switzerland	1995	CO_2, CH_4, HFC, PFC, SF_6, N_2O, CO, NO_x, VOC, SO_2	Energy, Industry, Agriculture, Land Use/Forestry, Waste, Solvents	Switzerland 2nd National Communication [93]
Taiwan	1996	CO_2	Energy	Young, RT[94]
Thailand	1994	CO_2, CH_4, N_2O, CO, NO_x, VOC	Energy, Industry, Agriculture, Land Use/Forestry, Waste	Thailand National Communication[95]
	1990	CO_2, CH_4, N_2O,CO, NO_x,	Energy, Industry, Agriculture, Land Use/Forestry, Waste	Climate Change Asia website[22]

* Year of most recent inventory.
** Unless otherwise specified, the Energy sector includes all stationary and mobile combustion sources, and Agriculture includes biomass burning.

Table 1. Emissions Inventories for Climate Forcing Pollutants (continued)

Inventory and description	Year *	Pollutants included	Source Categories **	Reference
Turkmenistan	1994	CO_2, CH_4, N_2O, CO, NO_x, VOC, SO_2	Energy, Industry, Agriculture, Land Use /Forestry, Waste, Solvents	Turkmenistan National Communication[96]
United Kingdom	1994	CO_2, CH_4, HFC, PFC, SF_6, N_2O, CO, NO_x, VOC	Energy, Industry, Agriculture, Land Use/Forestry, Waste, Solvents	UK 2nd National Communication[97]
United States	1995	CO_2, CH_4,HFC, PFC, SF_6, N_2O, CO, NO_x, VOC	Energy, Industry, Agriculture, Land Use/Forestry, Waste, Solvents	US 2nd National Communication[98]
Uruguay	1994	CO_2, CH_4, N_2O, CO, VOC	Energy, Industry, Agriculture, Land Use/Forestry, Waste, Solvents	Uruguay National Communication[99]
Uzbekistan	1994	CO_2, CH_4, N_2O, CO, NO_x, VOC, SO_2	Energy, Industry, Agriculture, Land Use/Forestry, Waste	Uzbekistan National Communication[100]
Vanatua	1994	CO_2, CH_4, N_2O, CO	Energy, Agriculture, Land Use/Forestry	Vanatua National Communication [101]
Zimbabwe	1994	CO_2, CH_4, N_2O, CO, NO_x	Energy, Industry, Agriculture, Land Use/Forestry	Zimbabwe National Communication [102]

* Year of most recent inventory.
** Unless otherwise specified, the Energy sector includes all stationary and mobile combustion sources, and Agriculture includes biomass burning.

European Environment Agency (EEA)

The European Environment Agency (EEA)[8] provides an environmental information system to help the European Community attain sustainable development and integrate environmental aspects into economic policies. As part of its services, the agency's website provides downloadable data sets used in technical reports. Available data include emissions inventories from the European Community on a country-specific as well as regional basis. These inventories were reported to the LRTAP as well as the UNFCCC conventions.

U.S. Department of Energy Energy Information Administration (EIA)

The Energy Information Administration (EIA)[9], created by Congress in 1977, is a statistical agency of the U.S. Department of Energy. They provide policy-independent data, forecasts, and analyses to promote sound policy making, efficient markets, and public understanding regarding energy and its interaction with the economy and the environment. They obtain data primarily from surveys of companies engaged in energy-related businesses such as domestic natural gas and electric utilities, oil refineries, petroleum marketers, coal mines, government agencies, and energy end users such as manufacturers and households.

Global Emission Inventory Activity (GEIA)

The Global Emission Inventory Activity (GEIA)[10] was created in 1990 to develop and distribute global natural and anthropogenic emissions inventories of gases and aerosols. It is a component of the International Globa Atmospheric Chemistry (IGAC) project, which is a network of several hundred scientists working together to understand and predict issues such as ozone depletion and greenhouse warming.

Data sets must undergo extensive peer review in order to be accepted into the GEIA database. Such data sets reported here include CO_2, CH_4, CFC, N_2O, CO, NOx, VOC, SO_2, and reactive Cl. Black carbon and particulate organic carbon were also inventoried, as discussed below. Data are presented in a 1° x 1° grid for all pollutants, and references for each inventory are documented on the GEIA website.

Convention for Long-Range Transboundary Air Pollution (LRTAP)

The Convention for Long-Range Transboundary Air Pollution (LRTAP)[6] in Europe was the first internationally legally binding instrument to deal with problems of air pollution on a broad regional basis. It was signed in 1979 and entered into force in 1983. It has greatly contributed to the development of international environmental law and created the essential framework for controlling and reducing the damage to human health and the environment of transboundary air pollution (UNECE website).

As part of the initial LRTAP and five subsequent Protocols, European countries agreed to inventory greenhouse gas pollutants and precursors, sulfur emissions, ground-level ozone, heavy metals, persistant organic pollutants, and volatile organic compounds. Most countries use the CORINAIR methodology for their inventories, and report emissions using the Selected Nomenclature for sources of Air Pollution (SNAP).

RAINS-ASIA

The RAINS-ASIA project, sponsored by the World Bank and the Asian Development Bank, originally simulated acid deposition from fossil fuels and ambient pollutant concentrations in 94 Asian regions and 23 countries. The model has now expanded to incorporate biofuels, such as fuel wood, crop residue, and animal waste. Scientists such as David Streets, John A van Aardenne, and Jitendra Shah used this model to inventory greenhouse gases and precursors from biofuel[11] and fossil fuel combustion.[12, 13]

World Bank

In their World Development Indicators 2001 publication, the World Bank inventoried nitrogen dioxide, sulfur dioxide, and particulates in the major cities of 53 countries. Data are based on reports from urban monitoring sites and reported as annual means.[14]

Country-specific Greenhouse Gas Inventories

In addition to regional and global inventories, we found more than 80 country-specific inventories. The majority of these were developed as part of the UNFCCC using IPCC[4] or comparable methods. Recent efforts to assess and reduce greenhouse gas emissions in Asia have also resulted in country-specific inventories for that region. Table 1 summarizes these country inventories, including sectors and pollutants covered.

United Nations Convention on Climate Change (UNFCCC)

Country-specific greenhouse gas inventories are prepared under the UNFCCC[1]. The Convention was opened for signature in 1992, at the UN Conference on Environment and Development, or the “Earth Summit,” in Rio de Janeiro. Currently, 181 governments and the European Community are Parties to the UNFCCC. Parties meet regularly at the annual Conference of the Parties (COP) to review the implementation of the Convention.

In Article 4 of the UNFCCC, all Parties agreed to compile greenhouse gas inventories and publish them in periodic reports, or National Communications, to the COP. However, the Convention recognized that countries contribute differently to greenhouse gas emissions as well as their abilities to produce inventories. The Parties were therefore divided into three categories according to socio-economic status: Annex I, Annex II, and non-Annex I. Annex I includes both the relatively wealthy countries that were members of the Organization for Economic Cooperation and Development (OECD) in 1992, and countries with “economies in transition.” They are the industrialized countries who have historically contributed the most anthropogenic greenhouse gas emissions. These countries agreed to produce inventories within six months of “entry into force” of the Convention. They also agreed to adopt programs and policies that will limit anthropogenic emissions and enhance emissions sinks and carbon reservoirs.

The OECD members of Annex I are also listed in Annex II. These countries, including the United States, provide financial, technological, and research assistance to developing countries (non-Annex I) in fulfilling their obligations under the Convention. The non-Annex I countries may report greenhouse gases in more general terms, and they may submit their emissions inventories within a broader time frame than Annex I countries. They may, however, accept the responsibilities of Annex I parties at any time.

Countries inventoried the following greenhouse gases and precursors to greenhouse gas formation: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulfur dioxide (SO_2), nitrogen oxides (NOx), carbon monoxide (CO), and volatile organic carbon (VOC). Countries did not inventory sources of black carbon as part of the Convention, and very few inventoried particulate matter.

The Convention specified that inventories should include those greenhouse gases not included in the Montreal Protocol on Substances that Deplete the Ozone Layer, as those pollutants are already specifically reported and controlled. Since some pollutants included in the Protocol are also greenhouse gases, some countries included them in their inventories. These pollutants include chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6).

Climate Change Asia–ALGAS

The Asia Least-Cost Greenhouse Gas Abatement Strategy (ALGAS)[22], developed by the United Nations Development Program/Global Environmental Facility (UNDP/GEF), assessed the present levels of greenhouse gas emissions and reviewed options to reduce emissions in Asia. Participating countries included China, India, Indonesia, Korea, Mongolia, Myanmar, Pakistan, Philippines, Thailand, and Vietnam. The project inventoried CO_2, CH_4, N_2O,CO, and NOx, and emissions for each country using IPCC methods. Results of the study were reported to the UNFCCC as part of the convention agreements.

CHINA-MAP

CHINA-MAP was an international and multi-disciplinary program that assessed the effects of economic development and the regional environmental impacts it made on agriculture in China.[103] The program was led by the Chinese Academy of Sciences and the Georgia Institute of Technology, and sponsored by NASA. As part of the study, David Streets and Stephanie Waldhoff developed emissions profiles for SO_2, NOx, and CO for China for the years 1995 and 2020.[31] In this study, all sectors of the Chinese economy were considered, including biofuel combustion in rural homes. Much of the data needed to construct the inventory was obtained through the RAINS-ASIA model, which is described above.

Black Carbon and Organic Carbon Inventories

Most of the inventories identified in Table 1 focus on greenhouse gases. We also identified five regional and/or global emissions inventories that include black carbon (BC) particulate matter, and two that include organic carbon (OC) particulate matter. These inventories were published in scientific papers, and each one has been developed using a unique methodology. Table 2 specifies the source categories covered by each inventory, divided into residential, industrial, utility, mobile, industrial processes, and fire. We further discuss the methods used to develop these emissions factors in a later section.

Table 2. Global and Regional Emissions Inventories for Black Carbon (BC) and Organic Carbon (OC) Particulate Matter

Black Carbon Inventories			
CHINA-MAP	1995	Residential, Industry, Transport, and Power Fossil Fuel Combustion, Field Combustion	Streets, David G. et al[104]
Cooke and Wilson – Regional; global with 10° latitude x 10° longitude resolution	1996	Fossil Fuel and Biomass Combustion	Cooke and Wilson[105]
ECHAM4 – worldwide and regional/country with 3.75° latitude x 3.75° longitude resolution		Fossil Fuel Combustion	Cooke et al.[106]
GEIA – worldwide, 1° latitude x 1° longitude	1994	Fossil Fuel combustion, Biomass burning	GEIA online database[10]
Liousse et al. – global, 4.7° longitude x 7.5° latitude		Biomass burning of savannahs, tropical forests, agricultural fires, and domestic fuels; Fossil fuel combustion	Liousse et al.[107]
Organic Carbon Inventories			
ECHAM4 – worldwide and regional/country with 3.75° latitude x 3.75° longitude resolution		Fossil Fuel Combustion	Cooke et al.[106]
Liousse et al. – global, 4.7° longitude x 7.5° latitude		Biomass burning of savannahs, tropical forests, agricultural fires, and domestic fuels; Fossil fuel combustion	Louisse et al.[107]

CHINA-MAP

As another component of the CHINA-MAP program, David Streets et al.[104] produced an inventory for black carbon for the years 1995 and 2020. This inventory included 37 source categories, covering all fuel combustion activities in China except the use of gaseous fuels. The authors calculated emissions using fuel consumption data by sector and fuel type within the framework of the RAINS-Asia model. They compiled emissions factors from previously published data where available. If sufficient information existed, they also derived fractions of BC and fine particulate matter from total PM emissions. The central and high emission factors used in this study resulted from combining these data.

Cooke and Wilson

William Cooke and Julian Wilson[105] constructed a 10^{o} latitude x 10^{o} longitude global inventory for black carbon emissions. The inventory covers fossil fuel combustion and biomass burning. The authors assumed that all emissions were anthropogenic, and they did not account for differences between developed and less developed countries.

ECHAM4

William Cooke et al.[106] developed global inventories of black and organic carbon from fossil fuel combustion. They were calculated using the fourth generation atmospheric general circulation model, ECHAM4, from the Max Planck Institute. The version used in the study, T30, has an approximate resolution of 3.75^{o} longitude x 3.75^{o} latitude.[108]

The authors used published emissions factors and data sets to calculate both bulk (particles with diameters of greater than a few microns) and submicron emissions. They obtained fossil fuel consumption data from the *United Nations* (1993), and used 1984 as the reference year. The authors also distinguished between developed and less developed countries in order to characterize the combustion efficiency and emissions controls used in each country. Developed countries included those in the Organization for Economic Cooperative Development (OECD) in 1984. The semi-developed countries included those in the former Eastern European Bloc, the former USSR, South Africa, Israel, Hong Kong, Singapore, and Taiwan. All other countries were placed in the group of developing countries.

GEIA

As mentioned above, the GEIA database included an inventory for black carbon developed by J.E. Penner and H. Eddleman.[10] This inventory was developed using two distinct methods. The first method used measured ambient concentration ratios of BC and SO_2 at locations throughout the world. The authors demonstrated that BC to SO_2 ratios are well correlated at most sites and are relatively constant in any one economic region. The inventory was constructed using these ratios and previously published sulfur inventories. The second method used estimated emission factors and published fuel production for wood and bagasse burning, diesel fuel, and domestic and industrial coal use.

Liousse et al.[107]

These authors developed emissions inventories for black and organic carbon from biomass burning and fossil fuel combustion. The purpose of the study was to calculate global distribution of carbonaceous particles in the three-dimensional 4.5° $^{\circ}$ longitude

published inventories.

Health-Related Emissions Inventories

pollutants, including SO_2 $_X$, and CO. However, many countries and non-government

pollutants. These are not as readily available as climate change inventories because of the lack of a central system for organizing health-related inventories (as the UNFCCC does for climate

sponsored by the United Nations Institute for Training and Research (UNITAR).[109] provides a repository for all countries with a national PRTR inventory, in an online version or on CD-ROM. However, very few countries have compiled an inventory of this magnitude. The

Table 3 lists separate health-related emissions inventories that we have identified in the current project. However, this is a cursory first look at available information on international

following sections provide background information on the major databases listed in Table 3.

Pollutant Release Transfer Registers

Nations Conference on Environment and Development. Countries agreed at this conference that the public should have access to environmental data, and that governments and industries should

Council for the Organization for Economic Cooperation and Development (OECD) recommended that countries develop a Pollutant Release Transfer Register (PRTR). Registers

and are compiled in a common reporting format based on the OECD Guidance to Governments Manual for PRTRs.

The following countries have compiled a PRTR to date: Australia, Canada, Mexico, the Netherlands, Slovak Republic, United States, and the United Kingdom. These inventories are

World Bank

The World Bank's Industrial Pollution Prevention System (IPPS) is a database that

Toxic Intensities database, and pollution intensities from Mexico and China.

The toxic intensities database provides pollution intensities, or pollution per unit of

from the USEPA's Toxic Release Inventory.

The databases for Mexico and China estimate various pollution intensities at the 2, 3, and

4-digit ISIC levels. Mexico's inventory was provided by the Instituto Nacional de Ecologia. China's inventory was produced using the China Environmental Yearbooks for 1992, 1994, and 1996. The yearbooks were produced by China's State Environmental Protection Administration (SEPA).[111]

U.S. Emissions Inventories

The U.S. Environmental Protection Agency (EPA) publishes a number of databases and inventories for health related pollutants. In particular, the criteria pollutant subsystem of the National Emissions Inventory (NEI) provides emissions estimates for SO_2, VOC, NO_X, CO, PM_{10}, $PM_{2.5}$, ammonia (NH_3), and secondary organic aerosols (SOA)[112]. The NEI also includes a National Toxics Inventory (NTI) that gives emissions estimates for 188 hazardous air pollutants (HAPs).[112] Both the criteria pollutant section of the NEI and the NTI are designed to provide detailed comprehensive inventories, giving precise locations of major emission sources and county-level emissions estimates where precise locations cannot be provided. The EPA also produces a Toxics Release Inventory (TRI) that lists industrial emissions of about 650 toxic chemicals.

Opportunities for Technology Transfer

A comparison of Table 1 and Table 3 indicates that climate change inventories are much more widespread than specialized inventories of health-related pollutants. The country-specific climate change inventories generally include some health related pollutants, most notably SO_2, VOC, and $NO_{X.}$ (see Figure 1). However, these do not generally have the same spatial resolution as inventories of health-related pollutants.

There are opportunities for technology transfer in both directions. The widespread compilation of climate change emissions inventories has resulted in the development of emissions inventories for some criteria pollutants, at least at the national level. These estimates can be allocated to smaller spatial scales using a variety of spatial surrogates (such as population or land-use) or using raw activity data compiled for with the climate change inventory. The raw activity data can also be used to develop emissions estimates for additional criteria pollutants (such as $PM_{2.5}$) or for toxic air pollutants.

In the other direction, some of the tools that have been developed for health-related emissions inventories allow a broader source category coverage than is characteristic of climate change inventories. This is particularly true for the U.S. NEI. For instance, climate change inventories generally focus on fuel combustion and industrial sources, although they also include agricultural sources for CH_4 and N_2O and non-industrial sources of halogenated compounds. The NEI provides activity estimates for a number of additional categories, most notably forest fires and prescribed burning. These categories are purposefully excluded from the CO_2 portion of the climate change inventory for material balance (over the long term the net CO_2 flux for a forest or other ecosystem is assumed to be zero, unless there are permanent land use changes). However, fires do result in net emissions of CH_4, N_2O, and BC. These can be quantified using fire activity data compiled for health-related emissions inventories. In addition, the spatial and temporal allocation tools developed for health-related emissions inventories can provide more accurate distribution of climate change emission for modeling applications.

Table 3. Other Emissions Inventories for Health Related Pollutants

Inventory description	Year	Pollutants	Sectors	Reference
Australia National Pollutant Inventory	2000	83 Toxic, Criteria, and Heavy Metal Pollutants	Industrial	Australia NPI document[113]
Canada's Nataional Pollutant Release Inventory	1999	172 substance (by Chemical Abstract Service (CAS) Registry Number)	Industrial	Canada NPRI document[114]
China Pollutant Intensities	1995	SO2, Smoke, Dust	Industrial Pollutant Intensities	New Ideas in Pollution Regulation (NIPR) website[111]
Mexico Pollutant Intensities	1997	PT, SOx, CO, NOX, HC	Industrial (SIC code)	New Ideas in Pollution Regulation (NIPR) website[111]
Mexico Pollutant Release and Transfer Registry	1997-1998	178 Toxic, Criteria, and Climate Forcing Pollutants		Mexican PRTR document[115]
Netherlands Pollutant Release and Transfer Registry	1995-96	170 Toxic, criteria, climate forcing, and heavy metal pollutants	industry, public utilities, traffic, households, agriculture	Netherlands PRTR document[116]
Slovak Republic	1998	93 Toxic, criteria, climate forcing, and heavy metal pollutants	industry	Slovak Republic PRTR document[117]
Turkey, by major city	2000	9 VOC pollutants	none	Muezzinoglu, A.[118]
UK National Atmospheric Emission Inventory	1990-1999	29 Toxic, Criteria, Metal, and Climate Forcing Pollutants	Industrial	NAEI database online[119]
US National Emissions Inventory (NEI), including the National Toxics Inventory (NTI)	1996 and other years	VOC, NO_X, CO, PM, SO_2, NH_3, secondary organic aerosol	industry, public utilities, traffic, households, agriculture, wildland fire	NEI[112] and NTI online
US Toxic Release Inventory	Annual	app. 650 Toxic, Criteria, Metal, and Climate Forcing Pollutants	Industrial	US TRI document[120]
World Bank – Industrial pollution intensity dataset	1987	SO2, NO2, CO, VOC, PM-10, TSP	Industrial (SIC codes at 4 digits)	World Bank's New Ideas in Pollution Regulation (NIPR) websiteJanuary 24, 2002[111]
World Bank – Toxic Pollution Intensity Dataset		246 Toxic, Criteria, and Heavy Metal Pollutant Intensities	Industrial (ISIC codes at 2, 3, and 4 digits)	World Bank's New Ideas in Pollution Regulation (NIPR) website[111]

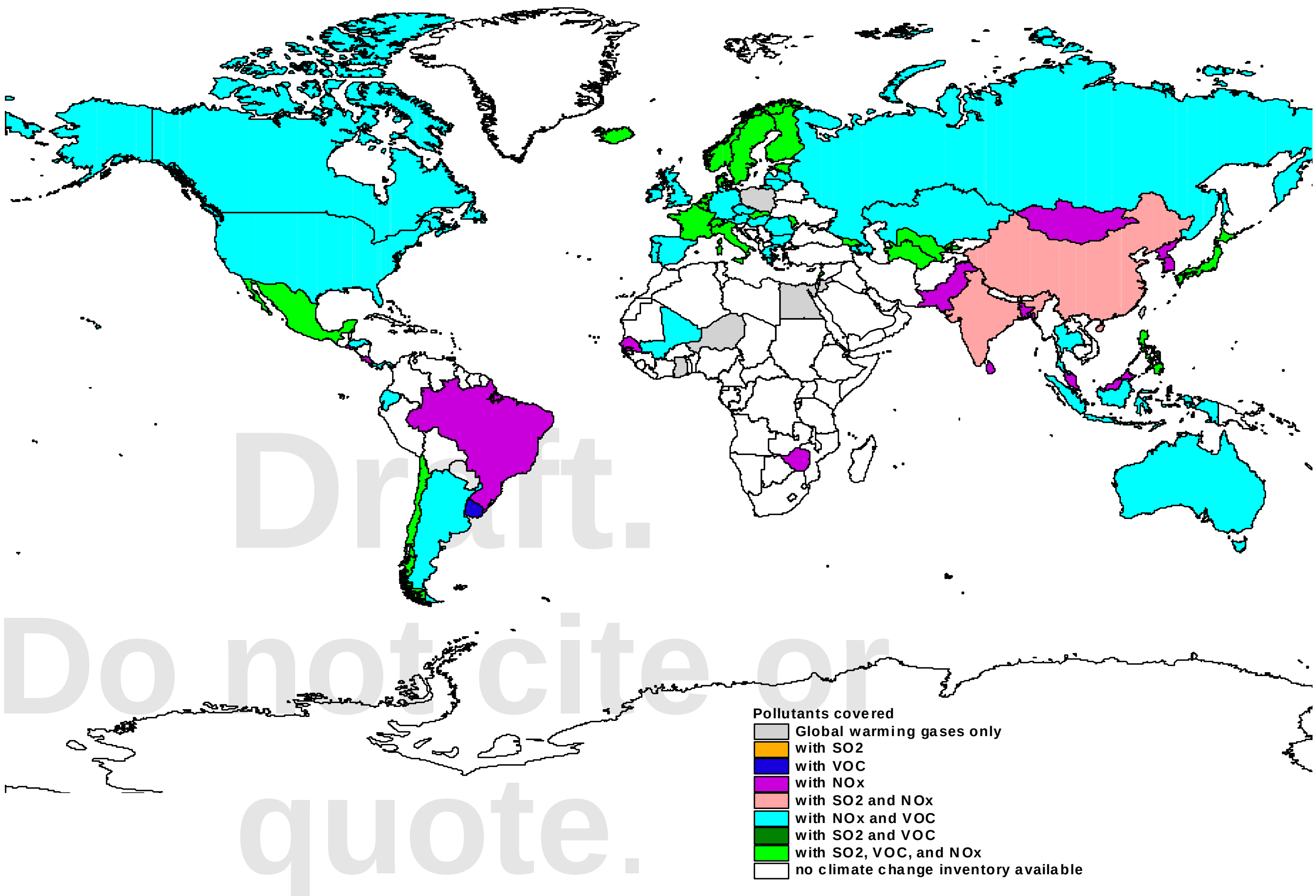

Figure 1. Health Related Pollutants Included in National Climate Change Inventories

Tools for Estimating Emissions of Black Carbon Particulate Matter

This section reviews existing emissions inventories for black carbon (BC) particulate matter, the tools used to produce these inventories, and other available tools. Uncertainties are evaluated and opportunities for improving BC emissions inventories are identified and prioritized.

Any analysis of BC emissions must recognize some unavoidable ambiguities in the definition of the pollutant. Carbon in particulate matter can take a variety of forms. Typically, these are divided into three main components: organic carbon (OC), a refractory component also known as elemental carbon (EC), and carbonate ion ($CO_3^{=}$). The split between EC and OC can be measured by different methods, but is typically obtained by measuring the amount that pyrolizes at different temperatures.[121] Soot generally falls in the EC fraction.

For the purposes of climate change emissions inventories, BC is defined as the carbon component of particulate matter that absorbs light. However, this specific component of particulate matter is difficult, if not impossible, to measure. Methods that measure light absorption in particulate matter assume that BC is the only light absorbing component present, while methods that rely on the partitioning of EC and OC use a somewhat arbitrary division point. For the purposes of this analysis, we have treated BC as roughly equivalent to EC. However, some components of OC may also be light-absorbing; in this case, inventories of BC and OC may overlap.

Table 4 compares emission factors used in existing BC inventories, as well as other available information on BC emissions. In many cases, BC emission factors were developed by combining BC speciation factors with appropriate particulate matter emission factors. Where possible, the table presents the BC speciation factors, the particulate matter emission factors, and the resultant BC emission factors. (In some cases, only an emission factor or a speciation factor is available.) Uncertainties are also given wherever possible. In addition to BC emission factors, Table 4 also includes OC emission factors, since the line between OC and BC is somewhat blurred. However, while some OC components may absorb light, most researchers presume that OC possesses optical properties that scatter solar radiation.[105, 107] Where possible, emission factors are given for BC and OC in particulate matter with an aerodynamic diameter of less than or equal to 2.5 microns ($PM_{2.5}$). In some cases, however, the literature used different measures, such as BC in $PM_{1.0}$ (submicron PM), or PM_{10} (less than or equal to 10 microns).

The following subsections discuss emission factors used in existing BC emissions inventories, and other tools for estimating BC emissions. The final subsection of this chapter discusses methods of ranking opportunities for improving BC emissions inventories.

Table 3. Emission Factors and Speciation Factors for BC and OC Fine Particulate Matter

Category	PM-2.5 (g/kg)	Uncer-tainty	BC content (%)	Uncer-tainty	BC-2.5 (mg/kg)	Upper limit	OC content (%)	Uncer-tainty	OC-2.5 (mg/kg)	Upper limit	Reference
Utility and industrial combustion - coal											
Previous inventories - China											
Utility pulverized burner, with fabric filter	0.66	0.99	2.5	0.5	2	6					Streets et al, 104
Utility pulverized burner, with ESP	0.66	0.99	0.5	0.5	0.1	0.5					Streets et al, 104
Utility pulverized burner, with scrubber	0.66	0.99	2.5	0.5	0.8	4					Streets et al, 104
Utility pulverized burner, with cyclone	0.66	0.99	1.5	0.5	0.2	2					Streets et al, 104
Utility pulverized burner, uncoltrolled	0.66	0.99	2.5	0.5	3	9					Streets et al, 104
Industrial pulverized burner, with ESP	0.66	0.99	0.5	0.5	0.1	3					Streets et al, 104
Industrial pulverized burner, with scrubbe	0.66	0.99	0.5	0.5	0.8	10					Streets et al, 104
Industrial pulverized burner, uncoltrolled	0.66	0.99	0.5	0.5	3	20					Streets et al, 104
Utility stoker, with scrubber	3.3	11.2	10	20	77	2,600					Streets et al, 104
Utility stoker, with cyclone	3.3	11.2	10	20	32	880					Streets et al, 104
Utility stoker, uncontrolled	3.3	11.2	10	20	320	4,400					Streets et al, 104
Industrial stoker, with scrubber	3.3	11.2	10	20	130	3,600					Streets et al, 104
Industrial stoker with cyclone	3.3	11.2	10	20	32	1,300					Streets et al, 104
Industrial stoker, uncontrolled	3.3	11.2	10	20	320	4,400					Streets et al, 104
Previous inventories - global											
Lignite, underdeveloped countries			25		1,800		25		5400		Cooke et al, 106
Lignite, semideveloped countries			25		590		25		1770		Cooke et al, 106
Lignite, developed countries			25		360		25		1080		Cooke et al, 106
Hard coal, underdeveloped countries			25		1,000		25		1000		Cooke et al, 106
Hard coal, semideveloped countries			25		325		25		325		Cooke et al, 106
Hard coal, developed countries			25		200		25		200		Cooke et al, 106
Other information											
Fingerprint test			3.3	3.8			9.4	14.8			Watson et al (a), 122
SPECIATE (uncontrolled)			0.9	0.1							SPECIATE, 123
Fabric filter			7.0	3.0			4.4	4.2			Houck et al, 124
Best estimate (for US)			5.1	3.4			6.9	9.8			

Table 3. Emission Factors and Speciation Factors for BC and OC Fine Particulate Matter

Category	PM-2.5 (g/kg)	Uncer-tainty	BC content (%)	Uncer-tainty	BC-2.5 (mg/kg)	Upper limit	OC content (%)	Uncer-tainty	OC-2.5 (mg/kg)	Upper limit	Reference
Utility and industrial combustion - oil											
Previous inventories											
Light distillate oil - China	0.15	0.12	55	25	70	210					Streets et al, 104
Middle distillate oil - China	0.45	0.49	55	25	250	730					Streets et al, 104
Residual oil - China	0.65	0.69	55	25	360	1,000					Streets et al, 104
Residual oil - general					10						Cooke & Wilson, 105
Other information											
SPECIATE			7.4	5.4			4.5	3.1			SPECIATE, 123
Boiler fingerprint			0.0	0.1			0.1	0.1			Watson et al (b), 125
Glass furnace fingerprint			0.78	0.82			2.4	1.9			Watson & Chow, 126
Utility and industrial combustion - natural and process gas											
Previous inventories											
Natural gas					0.4						Cooke & Wilson, 105
Process gas					0.06						Cooke & Wilson, 105
Natural gas and process gas					0.013				0.026		Cooke et al, 106
Utility and industrial combustion - wood and biofuel											
Previous inventories and compilations											
Biofuel, general	11	9	12		1,300	2,400					Liousse et al, 107
Biofuel - China	3.6	32.4	25	35	1,000	10,000					Streets et al, 104
Other information											
AP-42 particulate	0.03	0.15									AP-42, 127
SPECIATE			3.1	1.6			7.1	2.4			SPECIATE, 123

Table 3. Emission Factors and Speciation Factors for BC and OC Fine Particulate Matter

Category	PM-2.5 (g/kg)	Uncer-tainty	BC content (%)	Uncer-tainty	BC-2.5 (mg/kg)	Upper limit	OC content (%)	Uncer-tainty	OC-2.5 (mg/kg)	Upper limit	Reference
Residential combustion - coal											
Previous inventories											
Hard coal - China	7.2	51.3	50	30	3,700	20,000					Streets et al, 104
Hard coal - developing countries			25		4,550		25		9450		Cooke et al, 106
Hard coal - developed countries					2,780				5830		Cooke et al, 106
Hard coal - general					10,000						Cooke & Wilson, 105
Lignite - developing countries					8,180				24500		Cooke et al, 106
Lignite - developed countries					5,000				15000		Cooke et al, 106
Lignite - general					10,000						Cooke & Wilson, 105
Other information											
Fingerprint test			26.1	15.6			69.5	19.2			Watson et al (a), 122
Residential wood combustion											
Fireplace combustion											
Pine	9.5	1.0	1.4	0.1	130	160	56	2.8	5300	6200	Shauer et al (a), 128
Paper birch	2.7	0.0	22.0	2.9	590	670	86.8	6	2300	2500	Shauer et al (a), 128
Eastern hemlock	3.7	0.4	5.4	0.9	200	260	102.3	6.4	3800	4500	Shauer et al (a), 128
Red maple	3.3	0.3	6.7	1.9	220	310	85.5	5.8	2800	3300	Shauer et al (a), 128
Balsam fir	4.8	0.5	7.0	0.8	340	410	106.3	6.5	5100	6000	Shauer et al (a), 128
Oak	5.1	0.5	3.2	0.2	160	190	59	3	3000	3500	Shauer et al (a), 128
Northern red oak	5.7	0.6	3.8	0.7	220	280	87.5	5	5000	5800	Shauer et al (a), 128
Fireplace combustion Eastern White Pine	11.4	2.0	31.3	2.8	3,600	4,600	73.4	6.4	8400	10700	Shauer et al (a), 128
Eucalyptus	8.5	0.8	2.6	0.2	220	260	43.7	2.2	3700	4300	Shauer et al (a), 128
Fireplaces profiles - SPECIATE			21.2	23.2			45.2	7.8			SPECIATE, 123
Other residential wood											
Woodstoves profiles - SPECIATE			8.4	3.7			40.9	7.6			SPECIATE, 123
Average fingerprint, Denver CO			12.4	4.2			51.4	11.7			Watson et al (a), 122
Average fingerprint			19	7			64	7			Houck et al, 124
Overall - best estimate	6.1	2.9	11.1	9.7	675	1,879	69.4	22.4			

Table 3. Emission Factors and Speciation Factors for BC and OC Fine Particulate Matter

Category	PM-2.5 (g/kg)	Uncer-tainty	BC content (%)	Uncer-tainty	BC-2.5 (mg/kg)	Upper limit	OC content (%)	Uncer-tainty	OC-2.5 (mg/kg)	Upper limit	Reference
Residential combustion - other fuels											
Oil - previous inventories											
Heavy oil - China	0.65	0.69	55	25	360	1,000					Streets et al, 104
Kerosene - China	0.15	0.118	55	25	70	210					Streets et al, 104
Oil - general					80						Cooke & Wilson, 105
Oil - general					2,000						Cooke & Wilson, 105
Natural gas - previous inventories											
General					50						Cooke & Wilson, 105
General					0.137001				0.685004		Cooke et al, 106
Natural gas - other information											
Appliances - SPECIATE			6.7				84.9				SPECIATE, 123
Charcoal - previous inventories											
Briquettes - China	0.4	1.2	30	20	120	740					Streets et al, 104
Charcoal - general	10		15		1,500	1500					Liousse et al, 107
Charcoal - other information											
Meat charbroiling	18.8	2	0	0.5	0	100	33.8	2	6,400	7,400	Shauer (b), 129
Charcoal cooking			2.8	1.5			64.6	9.2			Watson & Chow, 126
Other fuels											
Dung burning					1,000						Liousse et al, 107
Peat					670				6,070		Cooke et al, 106

Table 3. Emission Factors and Speciation Factors for BC and OC Fine Particulate Matter

Category	PM-2.5 (g/kg)	Uncer-tainty	BC content (%)	Uncer-tainty	BC-2.5 (mg/kg)	Upper limit	OC content (%)	Uncer-tainty	OC-2.5 (mg/kg)	Upper limit	Reference
Gasoline vehicles and trucks											
Previous inventories											
Underdeveloped countries					15				730		Cooke et al, 106
Semideveloped countries					15				730		Cooke et al, 106
Developed countries					30				70		Cooke et al, 106
China	0.221	0.14	32	0	80	210					Streets et al, 104
Dynamoneter tests											
High emitting vehicles - southern Californ	0.72	1.34	29	18	210	980	71	18	510	1,830	Cadle et al (a), 130
Light duty vehicles 1986-96 models - Den	0.15		27		42		50		77		Cadle et al (b), 131
Light duty vehicles - high emitters - Denve	3.26		9		290		44		1,400		Cadle et al (b), 131
MOBILE model - light duty vehicles	0.031										EPA NEI, 111
MOBILE model - heavy duty vehicles	0.048										EPA NEI, 111
MOBILE model - light duty trucks	0.022										EPA NEI, 111
Field tests											
Tunnel, 1993, Switzerland - light duty	0.097	0.006	19	3.5	18	20					Weingartner et al, 132
Tunnel, 1997, California - light duty vehic	0.110	0.01	32	6	35	38	48	12	53	61	Kirchstetter et al, 133
Tunnel, 1993, California - light duty vehic	0.068	0.024	60	38	41	49	73	32	50	51	Allen et al, 134
Tunnel, 1993, California - light duty vehic	0.073	0.051	21	218	15	86	53	132	39	61	Allen et al, 134
Tunnel test 1993, California					157	174					Fraser, 135
Fingerprint - Arizona			14	8.0			30	12			Watson et al (b), 125
Fingerprint - Imperial county, California			18	5.8			49	19			Watson & Chow, 126
Fingerprint - Arizona			37	11			39	19			Watson et al (b), 125
Fingerprint - Colorado			40	16			57	26			Watson et al (a), 122
Fingerprint - Mexicali, Mexico			19	7.9			50	29			Watson & Chow, 126
Fingerprint 1997 - Paris			43	20							Ruellan et al, 136
Fingerprint - Australia			27				9.4				Chan et al, 137
SPECIATE			18	14			56	39			SPECIATE, 123
Average of fingerprints	0.031		27	15	8	13	41	30	13	22	
Best estimates											
Gasoline vehicles, developed countries			27	33	45	174	48	37	46	100	

Table 3. Emission Factors and Speciation Factors for BC and OC Fine Particulate Matter

Category	PM-2.5 (g/kg)	Uncer-tainty	BC content (%)	Uncer-tainty	BC-2.5 (mg/kg)	Upper limit	OC content (%)	Uncer-tainty	OC-2.5 (mg/kg)	Upper limit	Reference
Diesel vehicles and trucks											
Previous inventories											
Underdeveloped countries			66	13	10,000				5000		Cooke et al, 106
Semideveloped countries			66	13	10,000				5000		Cooke et al, 106
Developed countries			66	13	2,000				1000		Cooke et al, 106
China	1.43	2.7	52	0	1,100	2,500					Streets et al, 104
Dynamoneter tests											
Diesel truck (1999 Ford F250)					850	884			408	442	Moosmuller et al, 138
Diesel truck (1996 Dodge Ram 2500)					329	340			397	431	Moosmuller et al, 138
1995 turbocharged intercooled engine			36.4				32				Shi et al, 139
Medium duty diesel trucks - 1999	1.6	0.2	30.8	2.6	480	580	19.7	1.6	310	370	Shauer (c), 140
Light duty diesel 1996 - Denver	6.0		27		1,600		18		1,100		Cadle et al (b), 131
MOBILE model average	0.53										EPA NEI, 111
Field tests											
Tunnel test 1997 - heavy duty diesels (CA	2.5	0.2	52	16	1,300	1,600	20	3	500	540	Kirchstetter et al, 133
Tunnel test 1993 - heavy duty vehicles (C/	2.68	0.19	56	6.3	1,518	1,582	32	2.6	848	857	Allen et al, 134
Tunnel test 1993 - heavy duty vehicles (C/	1.53	0.28	61	38	936	1,330	39	16	588	713	Allen et al, 134
Tunnel, Switzerland, 1993 - diesel	2.6	0.1	31	3.4	823	880					Weingartner et al, 132
Tunnel, Switzerland, 1993 - heavy duty*	2.1	0.1	32	2.4	687	719					Weingartner et al, 132
Fingerprint - Arizona			33	8.0	174		40	6.6	213		Watson et al (b), 125
SPECIATE - heavy duty diesel			50	7.2			31	7.1			SPECIATE, 123
SPECIATE - light duty diesel			60	12			30	10			SPECIATE, 123
Best estimates											
Diesel vehicles, developed countries			48	18	1,100	1,600	29	10	645	900	

Table 3. Emission Factors and Speciation Factors for BC and OC Fine Particulate Matter

Category	PM-2.5 (g/kg)	Uncer-tainty	BC content (%)	Uncer-tainty	BC-2.5 (mg/kg)	Upper limit	OC content (%)	Uncer-tainty	OC-2.5 (mg/kg)	Upper limit	Reference
Aircraft											
Previous inventories											
Jet fuel					1,000				450		Cooke et al, 106
Aviation gasoline					100				1150		Cooke et al, 106
Other information											
Jet engines					110	150					Petzold et al, 141
Jet engines - SPECIATE			70.1				25.9				SPECIATE, 123
Wildland fires											
Previous inventories											
Forest fires - general	18	10	8.5		1,500	2,400					Liousse et al, 107
Tropical and subtropical					1,100						Cooke & Wilson, 105
Cold-deciduous forest with evergreens					750						Cooke & Wilson, 105
Cold-deciduous woodland					500						Cooke & Wilson, 105
Cold-deciduous forest without evergreens					600						Cooke & Wilson, 105
Temperate, various					500						Cooke & Wilson, 105
Evergreen broad-leaved sclerophyllous					1,100						Cooke & Wilson, 105
Xeromorphic (cactus)					1,100						Cooke & Wilson, 105
Grassland					500						Cooke & Wilson, 105
Savannah fires	8.1	5.5	10		810	1,360					Liousse et al, 107
Field tests											
Prescribed burning, Pacific Northwest			6.6	4.8	792	1,655	55	7.6	6,552	12,976	Ward & Hardy (a), 142
Chaparral, Southern California			9.0	3.4	610	739	51	7.8	3,675	4,441	Ward & Hardy (b), 143
Cerrado, Brazil			3.3		130						Kaufman et al, 144
Forest, Brazil			10		1,050						Kaufman et al, 144
Forest, fingerprint			3.2	1.8			47	15.7			Watson et al (a), 122
SPECIATE			6.9	5.5			56	8.7			SPECIATE, 123
Best estimates			7.2	4.5	730	1,430	54	7.7	5,800	11,500	

Table 3. Emission Factors and Speciation Factors for BC and OC Fine Particulate Matter

Category	PM-2.5 (g/kg)	Uncer- tainty	BC content (%)	Uncer- tainty	BC-2.5 (mg/kg)	Upper limit	OC content (%)	Uncer- tainty	OC-2.5 (mg/kg)	Upper limit	Reference
Agricultural burning											
Previous inventories											
Sugar cane burning - developing countries	7.0		11.0		770	770					Liousse et al, 107
Surgar cane burning - developed countries	5.0		15.5		780	780					Liousse et al, 107
Corn straw burning - China					720	7,200					Streets et al, 104
Corn and sugar cane - developing countrie	12.0		8.0		960	960					Liousse et al, 107
Corn and sugar cane - developed countries	5.0		14.0		700	700					Liousse et al, 107
Wheat straw burning - China					900	9,000					Streets et al, 104
Wheat and other grains - developing count	1.2		10.0		120	120					Liousse et al, 107
Wheat and other grains - developed countr	7.0		13.0		910	910					Liousse et al, 107
Rice straw burning- China					580	5,800					Streets et al, 104
Rice - developing countries	5.3		16.3		860	860					Liousse et al, 107
Rice - developed countries	2.5		24.0		600	600					Liousse et al, 107
Fingerprint tests											
Asparagus field burning			4.4	1.6			56	15.0			Watson & Chow, 126
Field burning - San Joaquin Valley, CA			12.0	7.0			44	10.0			Houck et al, 124
Field burning - Southern California, PM-10			10.9	3.3			35	8.0			Watson et al (b), 125
Field burning - SPECIATE data base			7.6	1.9			35	6.7			SPECIATE, 123
Best estimates			12.2	5.9	713	961	42	9.9			

Table 3. Emission Factors and Speciation Factors for BC and OC Fine Particulate Matter

Category	PM-2.5 (g/kg)	Uncer-tainty	BC content (%)	Uncer-tainty	BC-2.5 (mg/kg)	Upper limit	OC content (%)	Uncer-tainty	OC-2.5 (mg/kg)	Upper limit	Reference
Geological											
Paved road dust											
Denver, CO			0.8	0.5			7.4	2.8			Watson et al (a), 122
San Joaquin Valley, CA			2.0	1.0			18.0	2.0			Houck et al, 124
Southern CA			2.5	1.4			31.4	11.6			Watson et al (b), 125
SPECIATE			1.5	0.9			12.0	5.5			SPECIATE, 123
Best estimate			1.7	1.1			17.2	10.6			
Unpaved road dust											
Denver, CO			0.5	0.2			4.6	2.2			Watson et al (a), 122
SPECIATE - Pocatello, Idaho			1.5	1.3			2.1	1.6			SPECIATE, 123
Best estimate			1.0	0.9			3.4	2.3			
Agricultural soil											
Imperial Valley, CA			<0.2				1.5	1.1			Houck et al, 124
Denver, CO			<0.6				1.7	1.8			Houck et al, 124
Confined Animal Feeding Operations											
San Joaquin Valley, CA			6	2			31	13			Houck et al, 124
Other											
Soil dust - SPECIATE			0.6	0.72			4.3	3.6			SPECIATE, 123
Construction			0	0.51			0	1.4			Watson et al (b), 125
Construction			0	0.51			0	1.4			Watson et al (b), 125

Factors Used in Existing BC Inventories

Cooke and Wilson

In developing their black carbon inventory, Cooke and Wilson used published emissions factors and data sets for fossil fuel and biomass combustion. Emission factors for biomass combustion were calculated using a GISS surface-type data set and country-specific data on areas of forests and grasslands burnt per year. Fossil fuel emission factors used 1950-1991 data from the UN, and used 1984 as the reference year.

The authors assumed several things in calculating this inventory. When reliable data were unavailable, emissions were assumed to be zero. All emissions were assumed to be anthropogenic, due to lack of data from lightning-initiated fires. They did not account for combustion efficiency differences between sectors, nor did they consider economic differences between countries.

ECHAM4

As described in a previous section, Cook, Liousse, and Cachier used published emissions factors and data sets to calculate both bulk (particles with diameters of greater than a few microns) and submicron black and organic carbon emissions. The methods used in this paper were based on those used in the Cooke and Wilson study described above. The authors combined total particulate matter and BC emission factors in order to extrapolate black carbon emission factors for various sectors. Because OC emission factors had previously only been reported for developed countries, the authors used a ratio of OC to BC for each fuel type to scale the emission factor of OC for the same consumption sector for other countries.

This study differed from the previous one in that the authors distinguished between countries, combustion processes, and particle sizes. As described above, developed countries included those in the OECD, semi-developed countries were former members of the Eastern European Bloc, and all others were classified as developing countries. In addition, the authors calculated both bulk and submicron emissions factors in this study. They hypothesized that these two emissions types would better represent the upper and lower limits of global emissions impacts, since submicron emissions are capable of long-range transport. Bulk emission factors were derived from uncontrolled emission factors, and submicron factors were developed assuming an average of 50% of emissions reductions from control devices in developed countries.

The authors averaged data from EPA and other authors to develop submicron and bulk emissions for industrial, domestic, and combined/mobile combustion sources. The average emission factor represented domestic and industrial fossil fuel use in developed countries. The maximum in the range of factors represented domestic fuel use in semi-developed and underdeveloped countries. Industrial emission factors for underdeveloped countries were assumed to be five times that of developed countries. In all cases, the combined sector was calculated as the square root of the product of the domestic and industrial emission factors.

GEIA

Penner and Eddleman developed their global BC inventory using two distinct methods. The first method used measured ambient concentration ratios of BC and SO_2. The authors determined that BC and SO_2 emissions are highly correlated and fairly constant within distinct economic regions. They multiplied known SO_2 emissions in a particular region by the BC/SO_2 ratio for that region in order to determine BC emissions. The second method used estimated emission factors and published fuel production and use data.

CHINA-MAP

Streets and Waldhoff developed a black carbon inventory for China using fuel consumption data and detailed BC emission factors. Fuel data by sector and fuel type was obtained from the RAINS-Asia model. These data are provincial-level estimates compiled from official Chinese statistics.

The authors conducted a literature survey to obtain emission factors. They expanded upon these by calculating BC factors from total particulate matter emission factors. When sufficient information existed, they derived the submicron fraction of total particulate emissions from uncontrolled burning, and the BC fraction of the submicron particles. The authors then calculated central and high values from the tabulated factors, and produced controlled emission factors for each sector by applying removal efficiencies for each type of control device to the uncontrolled emission factor. Central emission factors were calculated using a geometric average of the measurements. High values represented the highest reported measurements, and indicated a worst-case scenario for China's BC emissions.

Louisse et al.

In developing black and organic carbon emissions factors for biomass burning and fossil fuel combustion, the authors reevaluated factors from previously published studies using recent analyses of fuel type, fuel amount, and combustion efficiency.

Other Tools for Estimating Black Carbon Emissions

A great deal of work has been done over the last 20 years to analyze the chemical makeup of respirable particulate matter, and to identify the important emission sources contributing to elevated levels of respirable particulate matter. As part of these efforts, researchers have taken "fingerprint" measurements of the chemical composition of particulate matter emitted by a wide array of sources. These fingerprints consist of speciation factors for different atomic elements and other components, expressed in terms of the mass fraction of a given component in particulate matter emissions. Most fingerprints include EC and OC, and as noted earlier, BC is roughly equal to EC.

EPA's SPECIATE database includes almost 200 measurements of the percentage of EC, OC, and other components of $PM_{2.5}$. Other sources of particulate fingerprint data include: the California Air Resources Board (CARB) speciation manual,[145] measurements carried out under the Northern Front Range Air Quality Study,[146] and data compiled by Desert Research Institute.[147] BC emission factors can be estimated by applying EC speciation factors to $PM_{2.5}$ emission factors, from sources such as EPA's Compilation of Emission Factors (AP-42). Alternatively, speciation factors can be applied directly to the $PM_{2.5}$ emissions inventories to estimate BC emissions. In addition, separate EC emissions estimates have been published for a number of emission source types as a result of fingerprint analyses.

Ranking Opportunities for Improving Black Carbon Emissions Inventories

As the scientific community becomes more aware of the importance of global BC emissions, the need for more complete and comprehensive inventories of this pollutant increase. Table 5 summarizes the emission source categories covered by current BC emissions inventories. The table illustrates that the existing inventories focus on industrial, utility, and residential combustion sources. Less attention is devoted to industrial process emissions, nonroad mobile source emissions, and categories such as open burning. These categories are candidates for additional attention in any effort to improve BC emissions inventories. However, the broad ranges variation in emission factors shown in Table 4 illustrate that considerable uncertainties exist even for stationary combustion sources. In many cases, these uncertainties could be reduced without additional measurements, by drawing on existing data to develop more detailed emission factors for specific subcategories of emission sources. In some cases, additional measurements may be needed.

Table 5. Source Categories Covered by Black Carbon Emissions Inventories

Source Category		Inventory				
		Cooke and Wilson	ECHAM4 (Cooke)	GEIA (Penner)	Louisse et al.	Streets et al.
Residential fuel	Coal	✓	✓[a]	✓	✓	✓
	Oil/diesel	✓	✓		✓	✓
	Biofuel	✓	✓	✓	✓	✓
	Natural Gas	✓	✓			
Industrial and utility fuel	Coal	✓	✓	✓		✓
	Oil	✓	✓			✓
	Biofuel	✓	✓	✓		✓
	Gas	✓[b]	✓			
	Petroleum	✓	✓			
	Kerosene	✓	✓			
On-road mobile	Diesel			✓		✓
	Gasoline	✓	✓			✓
Non-road mobile	Marine vessels					✓
	Aircraft	✓	✓			
	Other					✓
Fire	Wildland fire	✓			✓	
	Agricultural burning				✓	✓

[a] also includes briquettes, coke oven coke, gas coke, brown coal coke, lignite brown coal

[b] includes natural, blast furnace, coke-oven, gasworks, and refinery gases

The factors in Table 4 were used to make general calculations of U.S. and global BC emissions, in order to identify areas where improved emission factors would have the greatest impact. These calculations focused both on the relative magnitude of estimated BC emissions, and the relative uncertainty the estimates.

We estimated BC emissions for the U.S. by applying speciation factors for different emission categories (from Table 4) to $PM_{2.5}$ emissions estimates from the EPA's National Emissions Inventory.[112] These calculations are summarized in Table 6. The table shows the NEI $PM_{2.5}$ emissions estimate for each category, a best estimate and upper end estimate for the BC speciation factor, and a best estimate and upper end estimate for BC emissions. Table 7 ranks different emission source categories according to their contribution to total U.S. emissions, based both on the best estimate and the upper end estimate of emissions. Categories are also ranked based on the approximate magnitude of the uncertainty of BC emissions. The following equations were used in these evaluations:

$$C(B)_i = \frac{100 \times E(B)_i}{\sum_k E(B)_k}$$

$$C(U)_i = \frac{100 \times E(U)_i}{E(U)_i + \sum_{k \neq i} E(B)_k}$$

$$Unc_i = E(U)_i - E(B)_i$$

where:

subscripts i and k refer to source categories contributing to BC emissions

C(B) = best estimate of the contribution of a particular source category to total emissions (%)

C(U) = upper end estimate of the contribution of the particular source category to total emissions (%)

Unc = uncertainty of emissions estimate for the particular source category

E(B) = best estimate of emissions from a given category

E(U) = upper end estimate of emissions from a given category

$\sum_k$ refers to the sum over all source categories

$\sum_{k \neq i}$ refers to the sum over all categories except the particular source category i

Tables 8 and 9 show similar calculations for global BC emissions. We estimated global emissions in Table 8 by applying BC emission factors to fuel consumption figures, which for most categories were calculated from CO_2 emissions reported in the EDGAR climate change database.[7] In the case of wildland fires, fuel consumption was taken from an analysis by Hao and Ward.[148] It must be noted that the emissions in Table 8 are rough estimates developed without detailed activity data, for the purposes of ranking order of magnitude uncertainties. Table 9

Table 6. Estimated Breakdown of BC Emissions in the U.S.

Category	Reported US $PM_{2.5}$ emissions (1000 Mg/yr)	BC to $PM_{2.5}$ ratio (%) Best estimate	BC to $PM_{2.5}$ ratio (%) High estimate	Estimated BC emissions (1000 Mg/yr) Best estimate	Estimated BC emissions (1000 Mg/yr) High estimate
Electric utilities - coal	92	3.7	7.1	3.0	7.0
Electric utilities - petroleum	4.0	7.4	13	<0.1	<0.1
Electric utilities - natural gas	17	6.7	15	1.0	3.0
Electric utilities - wood/other	3.0	9.3	31	<0.0	1.0
Industrial combustion - coal	21	3.7	7.1	1.0	2.0
Industrial combustion - petroleum	22	7.4	13	2.0	3.0
Industrial combustion - natural gas	49	6.7	15	3.0	7.0
Industrial combustion - wood	44	9.3	31	4.0	14
Commercial combustion - coal	7.0	3.7	7.1	<0.1	<0.1
Commercial combustion - petroleum	4.0	7.4	13	<0.1	<0.1
Commercial combustion - natural gas	7.0	6.7	15	<0.1	1.0
Residential combustion - natural gas	13	6.7	15	1.0	2.0
Residential combustion - wood	340	6.1	9.0	21	31
Onroad diesel vehicles	151	43	59	65	89
Onroad gasoline vehicles	58	27	60	16	35
Marine transportation	36	43	59[a]	16	21
Locomotives - diesel	25	43	59[a]	11	15
Aircraft	25	70		17	25
Nonroad - gasoline	75	27	60[a]	20	45
Nonroad - diesel	211	43	59[a]	91	125
Miscellaneous fuel combustion	73	14	24	10	18
Wildfires	212	7.2	12	15	25
Prescribed forest burning	478	7.2	12	34	56
Agricultural burning	85	12	13	10	11
Open burning - residential	157	12	13[b]	19	21
Open burning - other	275	12	13[b]	34	36
Incineration - residential	28				28
Incineration - other	15				15
Industrial - metals processing	94	10	30	9.0	28
Industrial - asphalt manufacture	4.0				4.0
Industrial - peteoleum refining	12	0.3	0.4	<0.1	<0.1
Oil and gas production	1.0				1.0
Rubber and plastics products	2.0				2.0
Fugitive dust - unpaved roads	1,283	1.0	1.9	12	24
Fugitive dust - paved roads	620	1.7	2.8	11	17
Fugitive dust - construction	355		0.5		2.0
Fugitive dust - other	133	0.6	1.3	1.0	2.0
Agriculture - tilling	782		0.6		5.0
Agriculture - livestock	81	6.0	8.0	5.0	6.0
Total	5,894			433	727

a - Estimated based on information for onroad vehicles.

b - Estimated based on information for agricultural burning.

Table 7. Ranking of U.S. Source Categories by BC Emissions and Uncertainty

Category	Contribution to total U.S. BC emissions (%): Based on best estimate	Contribution to total U.S. BC emissions (%): Based on upper end estimate	Uncertainty of BC estimate (1000 Mg/yr)	Rankings of importance: Based on share of BC: Best estimate	Rankings of importance: Based on share of BC: Upper	Rankings of importance: Based on uncer-tainty
Electric utilities - coal	0.8	1.5	3.1			
Electric utilities - petroleum	0.1	0.1	0.2			
Electric utilities - natural gas	0.3	0.6	1.4			
Electric utilities - wood/other	0.1	0.2	0.6			
Industrial combustion - coal	0.2	0.3	0.7			
Industrial combustion - oil	0.4	0.6	1.2			
Industrial combustion - gas	0.8	1.7	4.1			
Industrial combustion - wood	1.0	3.1	9.8			
Commercial combustion - coal	0.1	0.1	0.2			
Commercial combustion - oil	0.1	0.1	0.2			
Commercial combustion - gas	0.1	0.2	0.5			
Residential combustion - gas	0.2	0.4	1.1			
Residential combustion - wood	4.8	6.9	9.8	5	7	10
Onroad diesel vehicles	15	19	24	2	2	4
Onroad gasoline vehicles	3.6	7.7	19	10	6	6
Marine transportation	3.6	4.9	5.8	9		
Locomotives - diesel	2.5	3.3	4.0			
Aircraft	4.0	5.6	7.4	8		
Nonroad - gasoline	4.7	9.8	25	6	4	3
Nonroad - diesel	21	27	34	1	1	1
Miscellaneous fuel combustion	2.4	4.0	7.3			
Wildfires	3.5	5.6	9.5		10	
Prescribed forest burning	7.9	12	22	3	3	5
Agricultural burning	2.4	2.6	0.8			
Open burning - residential	4.4	4.7	1.4	7		
Open burning - other	7.7	8.3	2.5	4	5	
Incineration - residential		6.1	28		9	2
Incineration - other		3.2	15			8
Industrial - metals processing	2.2	6.2	19		8	7
Industrial - asphalt manufacture		0.9	3.8			
Industrial - peteoleum refining	<0.1	<0.1	<0.1			
Oil and gas production		0.1	0.6			
Rubber and plastics products		0.5	2.0			
Fugitive dust - unpaved roads	2.9	5.4	12			9
Fugitive dust - paved roads	2.4	3.9	6.8			
Fugitive dust - construction		0.4	1.8			
Fugitive dust - other	0.2	0.4	1.0			
Agriculture - tilling		1.1	4.7			
Agriculture - livestock	1.1	1.5	1.6			

Table 8. Estimated Breakdown of Global BC Emissions

Source category	Reported global CO_2 emissions	BC emission factors (mg/kg) Best estimate	BC emission factors (mg/kg) Upper end	Estimated BC emissions (10^6 Mg) Best estimate	Estimated BC emissions (10^6 Mg) Upper end	Notes on emission factors
Fossil fuel combustion						
Industrial boilers	4,590	130	770	0.60	3.5	a
Power generation	6,638	130	770	0.86	5.1	b
Industrial process fuel	1,624	130	770	0.21	1.3	a
Residential, etc.	3,343	1,350	7,000	4.5	23	c
Road transport	3,261	570	1,360	1.9	4.4	d
Non-road land transport	343	500	1,600	0.17	0.55	e
Air (domestic and int'l.)	545	110	150	0.06	0.08	f
International shipping	350	200	1,150	0.07	0.40	g
Fossil fuel: non-combustion						
Gas flaring	260	0.01	0.03	<0.01	<0.01	h
Biofuel						
Industrial boilers	118	1,000	10,000	0.12	1.18	i
Other industry fuel use	1	1,000	10,000	0.00	0.01	i
Residentials etc.	427	675	1,880	0.29	0.80	j
Other						
Deforestation	1,837	730	1,430	1.3	2.6	j
Savannah fires (k)	5,200	130	500	0.68	2.6	j
Forest fires (k)	620	730	1,430	0.45	0.89	j
Total				21	90	

a Average of coal stoker, residual oil, and natural gas from Streets et al
b Average of coal stoker, pulverized coal, and residual oil from Streets et al
c Average of coal, oil, and natural gas from Streets et al
d Best estimate is average of best estimates from gasoline and diesel from Table 4, upper end estimate is average of gasoline and diesel from Streets et al
e Average of coal stoker, residual oil, and diesel from Streets et al
f Based on jet fuel factors from Petzold et al
g Average of coal stoker and residual oil from Streets et al
h Based on Cooke et al for natural gas combustion
i Based on Streets et al
j Based on averages from Table 4
k Biomass burned in wildland fire from Hao and Ward, 1993

Table 9. Ranking of Source Categories by Global BC Emissions and Uncertainty

	Contribution to global BC emissions (%)			Rankings of importance		
				Based on share of BC		
Category	Based on best estimate	Based on upper end estimate	Uncertainty of BC estimate (10^6 Mg/yr)	Best estimate	Upper	Based on uncer-tainty
Fossil fuel: combustion						
Industrial boilers	5.3	25	2.9	6	4	3
Power generation	7.7	33	4.2	4	2	2
Industrial process fuel	1.9	10	1.0	8	7	8
Residentials etc.	40	78	19	1	1	1
Road transport	17	32.1	2.6	2	3	4
Non-road land transport	1.5	4.7	0.4	9	10	10
Air (domestic + intern.)	0.5	0.7	<0.1			
International shipping	0.6	3.5	0.3			
Fossil fuel: non-combustion						
Gas flaring	<0.1	<0.1	<0.1			
Biofuel						
Industrial boilers	1.0	9.6	1.1	10	8	7
Other industry fuel use	<0.1	0.1	<0.1			
Residentials etc.	2.6	6.8	0.5	7	9	9
Other						
Deforestation	12	21	1.3	3	5	6
Savannah fires	6.0	20	1.9	5	6	5
Forest fires	4.0	7.6	0.4			

ranks different emission source categories according to their estimated contribution to total global emissions, and to their uncertainties.

Based on the calculations in Tables 6 and 7, the largest BC emission source categories in the U.S. are nonroad and onroad diesel emissions and prescribed forest burning. However, the most important categories in terms of the magnitude of uncertainty are nonroad diesel vehicle, residential incineration, and nonroad gasoline vehicles.

The global inventory categories available from EDGAR are much less detailed than the categories in the U.S. NEI. From Tables 8 and 9, the largest BC emission categories on a global basis are residential combustion, onroad vehicles, power generation, and deforestation (by burning). The most important categories based on the magnitude of uncertainty are residential combustion, industrial combustion, and utility combustion.

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